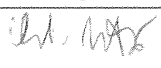






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Title: <b>FRACTURE CONTROL PLAN</b>			

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CHANGE RECORD			
ISSUE	DATE	CHANGE AUTHORITY	REASON FOR CHANGE AND AFFECTED SECTIONS
1	Jan 2005		First Issue



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## 1. SCOPE

### 1.1 PURPOSE

It is the policy of CARLO GAVAZZI SPACE S.p.A. to produce Space Systems with a high degree of safety. This is accomplished through good engineering practices in the design, analysis, inspections, testing, manufacturing and operation of Space Flight Structure.

The ACOP plan is written in response to Fracture Control Requirements of RD 14.

### 1.2 APPLICABILITY

This document establishes the Fracture Control Requirements applicable to the ACOP flight standard structural hardware under CARLO GAVAZZI SPACE responsibility.

Hardware is to be considered as “structural” if designed to loads, pressure or environments provide stiffness, stability, or support or maintain containment.

This documents provides procedures and criteria that fully implement the basic requirements presented in RD 14.


Requirements are applicable to all CARLO GAVAZZI SPACE activities. Tasks and activities requested by this plan, include but not limited to design, analyses and tests, materials selection, purchase and storage, manufacturing process control, quality control tests and non-destructive evaluation, operation and maintenance.

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## 2. DOCUMENTS

### 2.1 APPLICABLE DOCUMENTS

AD	Doc. Number	Issue / Date	Rev.	Title / Applicability
1	SSP 52000-IDD-ERP	D / 6/08/03		EXpedite the PROcessing of Experiments to Space Station (EXPRESS) Rack Payloads Interface Definition Document
2	NSTS/ISS 13830	C / 01/12/1996		Implementation Procedures for Payloads System Safety Requirements – For Payloads Using the STS & ISS.
3	JSC 26493	17/02/1995		Guidelines for the preparation of payload flight safety data packages and hazard reports.
4	SSP 50004	April 1994		Ground Support Equipment Design requirements
5	SSP-52000-PDS	March 1999	B	Payload Data Set Blank Book
6	SSP 52000-EIA-ERP	Feb. 2001	A	Express Rack Integration Agreement blank book for Express Rack payload
7	GD-PL-CGS-001	3 / 17/03/99		PRODUCT ASSURANCE & RAMS PLAN
8	SSP 52000 PAH ERP	Nov. 1997		Payload Accommodation Handbook for EXPRESS Rack
9	SSP 50184	D / Feb. 1996		Physical Media, Physical Signaling & link-level Protocol Specification for ensuring Interoperability of High Rate Data Link Stations on the International Space Program
10	SSP 52050	D / 08/06/01		S/W Interface Control Document for ISPR ***ONLY FOR HRDL, SECTION 3.4 ***
11	ECSS-E-40	A / April 1999	13	Software Engineering Standard
12	AMS02-CAT-ICD-R04	29/08/2003	04	AMS02 Command and Telemetry Interface Control document. Section AMS-ACOP Interfaces
13	SSP 52000-PVP-ERP	Sept. 18, 2002	D	Generic Payload Verification Plan EXpedite the PROcessing of Experiments to Space Station (EXPRESS) Rack Payloads
14	NSTS 1700.7B	Rev. B Change Packet 8 / 22.08.00		Safety Policy and Requirements for Payloads using the STS
15	NSTS 1700.7B Addendum	Rev. B Change Packet 1 01.09.00		Safety Policy and Requirements for Payloads using the International Space Station
16	SSP 52005	Dec. 10, 1998		Payload Flight equipment requirements and guidelines for safety critical structures
17	NSTS 18798B	Change Packet 7 10.00		Interpretation of NSTS Payload Safety Requirements
18	MSFC-HDBK-527	15/11/86	E	Materials selection list for space hardware systems Materials selection list data
19	GD-PL-CGS-002	1/ 12-02-99		CADM Plan
20	GD-PL-CGS-004	2/07-04-03		SW Product Assurance Plan
21	GD-PL-CGS-005	2/09-05-03		SW CADM Plan

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## 2.2 REFERENCE DOCUMENTS

RD	Doc. Number	Issue / Date	Rev.	Title
1	GPQ-MAN-02	1		Commercial, Aviation and Military (CAM) Equipment Evaluation Guidelines for ISS Payloads Use
2	BSSC (96)2	1 / May 96		Guide to applying the ESA software engineering standards to small software projects
3	GPQ-MAN-01	2 / Dec. 98		Documentation Standard for ESA Microgravity Projects
4	MS-ESA-RQ-108	1 / 28-Sep-2000		Documentation Requirements For Small And Medium Sized MSM Projects
5	PSS-05			Software Engineering Standards
6	GPQ-010	1 / May 95	A	Product Assurance Requirements for ESA Microgravity Payload. Including CN 01.
7	GPQ-010-PSA-101	1		Safety and Material Requirements for ESA Microgravity Payloads
8	GPQ-010-PSA-102	1		Reliability and Maintainability for ESA Microgravity Facilities (ISSA). Including CN 01
9	MIL-HDBK-5	G/1994		Metallic Materials and Element for Aerospace Vehicle Structures
10	NASA Reference Publication 1228	1/1990		Fastener Design Manual
11		June, 1973		E. F. BRUHN – Analysis & Design Of Flight Vehicle Structure
12	SSP 52000-IDD-ERP	E / 09/09/2003		EXpedite the PROcessing of Experiments to Space Station (EXPRESS) Rack Payloads Interface Definition Document
13	SSP 30558	30/06/1994	B	Fracture control requirements for space station
14	NASA-STD-5003	07/10/1996		Fracture control requirements for payloads using the space shuttle
15	SSP 52005	18/12/2002	C	

### 3. ACRONYMS AND ABBREVIATIONS

Acronyms	Full Text
ACOP	AMS-02 Crew Operation Post
EXPRESS	EXpedite the PProcessing of Experiments Space Station
DoF	Degree of freedom
FE	Finite Element
FSu	Ultimate Factor of Safety
FSy	Yield Factor of Safety
MDL	Mid Deck Locker
MoS	Margin of Safety
MoSu	Margin of Safety against ultimate failure
MoSy	Margin of Safety against material yielding
Rs	Shear load ratio
Rt	Tensile load ratio
RVLf	Random Vibration Load Factor

Items defined as potentially fracture critical are listed in the potentially fracture critical items list (PFCIL).

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## 4.2 ORGANIZATION

In order to implement the Fracture Control Plan (FCP) and assuring its effectiveness, a Fracture Control Engineer (FCE) shall be nominated. FCE is responsible for releasing the FCP, for the implementation of the Fracture Control Requirements (FCR) and for the performance and completion of all the Fracture Control Activities (FCA) on the “system”, necessary to comply with all FCR. The FCE is also responsible for monitoring, reviewing and approving all FCA performed internally and by the Subcontractors.

The FCE will establish a direct link with other members of the following organizations:

- System Engineer (SE)
- Safety
- Quality Assurance (QA)
- Manufacturing.

## 4.3 REVIEW AND DELIVERABLES

Fracture control related data should be developed during the engineering design, qualification and manufacturing process to support the following reviews:

### For a System Requirements Review (SRR)

The results of preliminary hazard analysis and fracture control screening and a written statement as to whether or not fracture control is applicable.

### For a Preliminary Design Review (PDR)

- 1) A written statement which either confirms that fracture control is required or else provides a justification for not implementing fracture control.
- 2) Identification of initial fracture control-related project activities, including:
  - scope of planned fracture control activities dependent upon the results of the hazard-analysis and fracture control screening performed;
  - definition and outline of the fracture control plan;
  - identification of primary design requirements/constraints.
  - list of potential fracture critical items.

### For a Critical Design Review (CDR)

- 1) A fracture control plan which has been approved by the customer.
- 2) Verification requirements for inspection procedures and personnel.
- 3) The status of fracture control activities, together with a specific schedule for completion of the verification activities.
- 4) A description and summary of the results of pertinent analyses and tests.
- 5) List of potential fracture critical items.

### For an Acceptance Review (AR)

- 1) A status report showing completion of all fracture control verification activities.
- 2) Relevant test, inspection and analysis reports.
- 3) List of potential fracture critical items.
- 4) List of fracture critical items.
- 5) List of fracture limited-life items.
- 6) Pressure-vessel summary log (for payloads of the NSTS, see NSTS 13830).

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## 5. IDENTIFICATION OF POTENTIALLY FRACTURE CRITICAL ITEMS

Fracture control screening shall be performed for the complete ACOP flight structure and components to identify potential fracture-critical items (PFCI) which shall be included in the potentially fracture-critical item list (PFCIL). It is necessary to determine whether a failure of a structural item will result in a catastrophic hazard, as defined in the safety analysis report. The structural screening shall be performed in a systematic way and shall be documented in a clear, concise and complete manner. The flowchart of Figure 4-1 shall be used.

Appropriate engineering data will be generated for all components and made available as a basis for fracture control classification.

Hazard analysis and structural screening shall be repeated, as necessary, in an iterative manner that takes design progress and design changes into account, in order to ensure that implementation of the fracture control plan is compatible with the current design and service-life scenario.

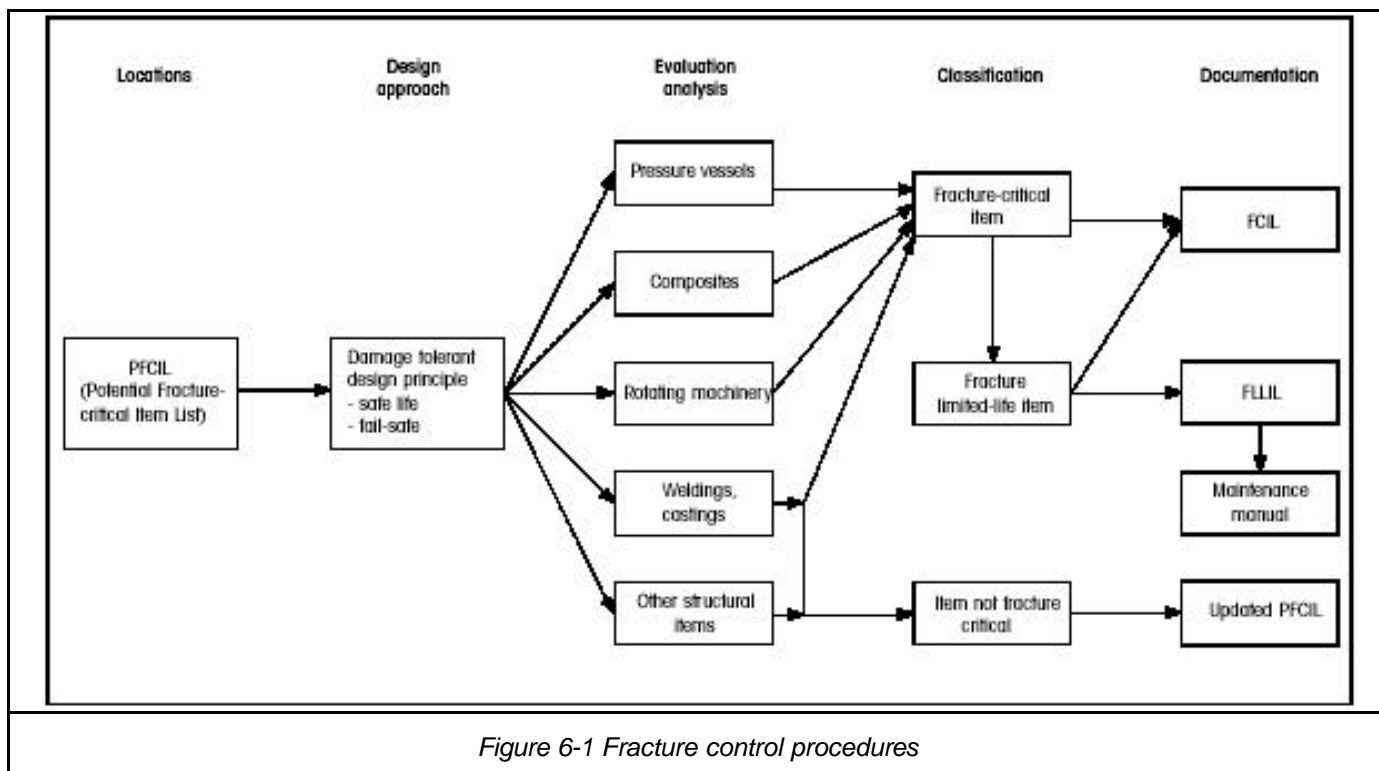
## 6. EVALUATION OF POTENTIALLY FRACTURE CRITICAL ITEMS


### 6.1 PFCI TYPE

ACOP PFCIs shall typically be divided into:

1. pressurized systems;
2. composites;
3. weldings and castings;
4. rotating machinery;
5. other items of which the structure is comprised.

Each PFCI shall be damage tolerant. For the evaluation the “safe life” logic or the “fail-safe” logic shall be used, depending on the design principle used. In addition, the special requirements defined in chapter **Errore. L'origine riferimento non è stata trovata.** shall be implemented.



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## 6.2 SELECTION OF PFCI CRITICAL LOCATIONS

The most critical locations on a PFCI shall be identified, to enable fracture analysis to be performed. The following parameters shall be considered as criteria for the selection of PFCIs:

- the maximum level of local stress;
- the range of cycling stress;
- locations to be analysed showing high stress intensities (correction function);
- areas where material fracture properties can be low;
- stresses which, combined with the environment, result in reduced fracture resistance.

If, as a result of the assessment, there is no obvious ranking in criticality, a sufficient number of locations shall be analysed to permit the criticality of the item to be defined.

## 6.3 DAMAGE TOLERANT DESIGN

There are two ways of implementing damage tolerance:

- Safe life**  
A PFCI is a safe life item if it can be shown that the greatest defect in the part will not grow to such an extent that the minimum specified performance (for example the limit-load capability or no-leak) is no longer assured within a safe life interval. The maximum sustained stress-intensity factor  $K_{max}$ , shall not exceed the threshold stress-intensity factor for stress-corrosion cracking  $K_{ISCC}$ .
- Fail-safe**  
A PFCI is a fail-safe item if it can be shown by analysis or test that, as a result of structural redundancy, the structure remaining after failure of any element of the PFCI can sustain the new higher loads with a safety factor 1.0 without losing limit-specified performance. In addition, the failure of the item shall not result in the release of any part or fragment which results in an event having catastrophic or critical consequences or which has a mass in excess of that stated as allowable.



### 6.3.1 SAFE LIFE COMPLIANCE PROCEDURE

The evaluation procedure to be followed for a PFCI considered as a safe life item is specified in the next figure. The term: “two flights” is required in order to take into account one aborted flight, i.e. the service life shall as a minimum include two ascent and one descent flight events.

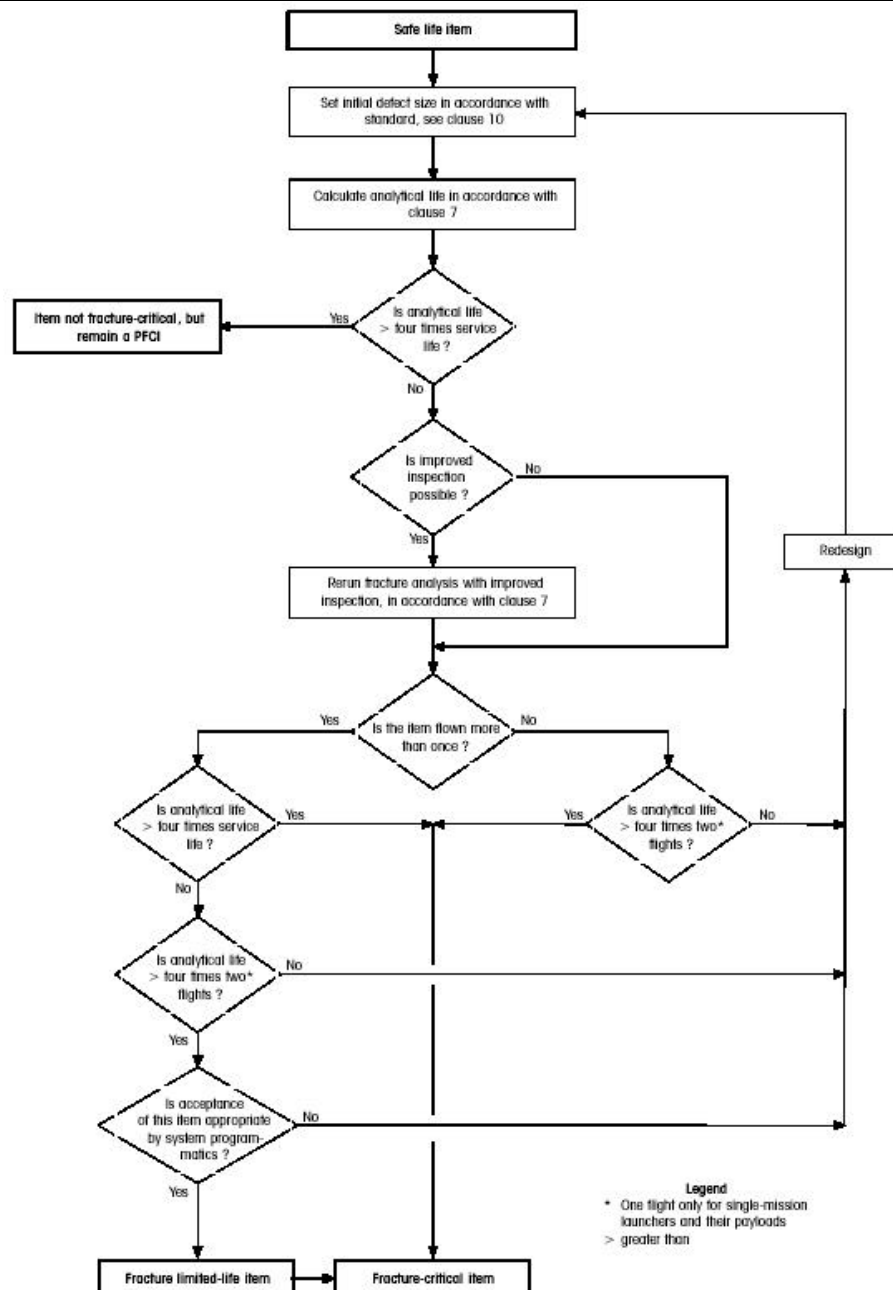



Figure 6-2 Safe life item evaluation procedure

*Figure 6-3 Evaluation procedure for fail-safe items*

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## 6.4 CONTAINED DESIGN

Any item that due to failure is not compliant with the requirements of chapter 5 shall be analyzed to demonstrate the contained design.

### 6.4.1 CONTAINED COMPLIANCE PROCEDURE

It shall be demonstrated by analysis or test that the release of any loose item which can lead to a hazard having serious or catastrophic consequences will be effectively prevented. For payloads of the NASA STS or ISS, it shall be shown by analysis or test that any loose item exceeding the allowable mass defined in chapter 5 will be prevented from being released into the cargo bay or crew compartments.

A reference approach can be found in RD 15 (punch equation Chapter 6.2.1).

## 6.5 LOW-RISK FRACTURE PART.

A low-risk fracture part shall comply with the requirements of 4.2.2.4.1 and 4.2.2.4.2 of RD 14 except for fasteners and shear pins, which need comply only with 4.2.2.4.3. of RD 14.

## 6.6 LOW RELEASED MASS PART

For a payload component to be classified as a low released mass part, it shall meet requirements a, b, and c listed below:

a. The part satisfies one of the following two conditions:

(1) Total mass of the part or any other released part is less than 0.25 pounds (113 grams).

(2) Total mass in pounds (kilograms) supported by the part is not more than  $14/h$ , where  $h$  is the part's travel distance in feet (or  $1.94/h$ , where  $h$  is in meters) to the aft bulkhead of the Space Shuttle cargo bay. When the installation location of a potential released mass is not known, a documented maximum travel distance estimate may be used. Total mass of the released part shall not exceed 2 pounds (0.9 kilograms).

b. It can be shown that the release of this component will not cause a catastrophic hazard to the Space Shuttle because of subsequent damage to the payload from which it came.

c. For parts which have low fracture toughness and are preloaded in tension, a fragment may be released at high velocity immediately following failure; therefore, the total released mass may not exceed 0.03 pounds (14 grams). A part shall be considered to have low fracture toughness when its material property ratio  $KIc/Fty < 0.33 \text{ in.}^{1/2}$  ( $1.66 \text{ mm}^{1/2}$ ), where  $KIc$  is the plane strain fracture toughness and  $Fty$  is the allowable yield tensile strength. If the part is a steel bolt and the  $KIc$  value is unknown, low fracture toughness shall be assumed when the specified minimum  $Ftu > 180 \text{ ksi}$  ( $1240 \text{ mPa}$ ), where  $Ftu$  is the allowable ultimate tensile strength.

## 6.7 CLASSIFICATION

The results of the safe life or fail-safe analysis, the type of non-destructive inspection used and the type of material used shall determine whether or not PFCIs are identified as fracture-critical items. A fracture-critical item (FCI) is defined as any of the following:

- any item which requires NDI better than standard NDI, as defined in chapter 9.1 ;
- any pressure vessel as defined in chapter **Errore. L'origine riferimento non è stata trovata.**;
- any item which requires periodic re-inspection in order to achieve the required life. Such items are called fracture limited-life items (FLLI) as a subset of FCI;
- any composite or non-metallic PFCI, unless contained.

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## 6.8 DOCUMENTATION REQUIREMENTS

The following documents shall be prepared and submitted to the customer for approval.

**a. Potential fracture-critical item list**

The potential fracture-critical item list (PFCIL) shall be compiled from the results of the fracture control screening and shall identify the item name, drawing number, material, design principle and required NDI (method/level) for each item.

**b. Fracture-critical item list**

The fracture-critical item list (FCIL) shall include the same information as the PFCIL. In addition, the FCIL shall specify a reference to the document which shows for each item the fracture analysis and/or test results and the analytical life.

**c. Fracture limited-life item list**

The fracture limited-life itemlist (FLLIL) shall include the same information as the FCIL. In addition, the FLLIL shall specify the inspection method and period, and shall identify the maintenance manual in which inspection procedures are defined.

## 6.9 TEST AND ANALYSIS REQUIREMENTS

An analysis of all PFCIs shall be performed and documented. When testing is used in addition to analysis the test method and test results shall also be documented.

The analysis and test documentation shall as a minimum contain the following:

**a. For safe life items:**


1. A description of the item with identification of material (alloy and temper), grain direction, and a clear sketch showing the size, location and direction of all assumed initial cracks.
2. A description of the analysis performed, including:
  - a reference to the stress report;
  - the loading spectrum and how it has been derived;
  - material data and how they have been derived;
  - environmental conditions;
  - stress intensity factor solutions and how they have been derived;
  - critical crack size;
  - analytical life.
3. A summary of the significant results.

**b. For fail-safe items:**

1. A description of the item.
2. Failure modes assumed.
3. Stress analysis with new loading distribution of the failed configurations and safety factor of 1.0.
4. Fatigue analysis of the most critical item.
5. A summary of the significant result.

**c. For contained items:**

1. A description of the assumed container, the assumed projectile dimensions, and the material-properties employed in the analysis.
2. A containment analysis, which includes the derivation of:
  - the velocity and energy of the projectile as it strikes the container;
  - all maximum forces or stresses in attachments, brackets and other relevant items occurring during impact;
  - a summary of the significant results.

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## 7. FRACTURE MECHANICS ANALYSIS

### 7.1 GENERAL

Fracture mechanics analysis shall be performed to determine the analytical life of a safe life item in accordance with the requirements. The data required to permit crack growth prediction and critical crack-size calculation are as follows:

- a. stress distribution;
- b. load spectra;
- c. material properties;
- d. initial crack size;
- e. stress intensity factor solutions.

### 7.2 ANALYSIS

- a. For the fracture mechanics analysis, the software package ESACRACK may be used. This package comprises the ESALOAD software, which generates load spectra, the fracture mechanics software NASGRO (NASA/FLAGRO), which includes a materials data base and the ESAFATIG software for fatigue analysis.
- b. In cases where it is not planned to use ESACRACK, alternative analysis procedures may be used if they are shown to give comparable results. Alternative analysis procedures shall be submitted to the customer for approval prior to their use.
- c. A fracture mechanics analysis shall include the following two items:
  1. crack-growth calculation;
  2. critical crack-size calculations.

### 7.3 ANALYTICAL LIFE PREDICTION

Analytical life prediction shall be performed on the basis of crack-growth analysis, which includes the followings:

**a. Identification of all load events experienced by the item in question:**

the service-life profile shall be clearly defined, in order to identify all cyclic and sustained load events. The following events shall be considered:

1. manufacturing/assembly;
2. testing;
3. handling, e.g. by a dolly or a hoist;
4. transportation by land, sea and air;
5. ascent (considering also abort landing and 2<sup>nd</sup> ascent);
6. stay in orbit, including thermally induced loads;
7. descent;
8. landing.

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**b. Identification of the most critical location and orientation of the crack on the item:**

for each item, only the most critical location and orientation of the crack needs to be analysed. To identify the most critical location, stress-concentration, environmental and fretting effects shall be considered (see also subclause 6.2.2). In cases where the most critical location or orientation of the initial crack is not obvious, the analysis shall consider a sufficient number of locations and orientations such that the criticality of the item can be defined.

**c. Derivation of detailed stresses for the critical location:**

for the critical location, stresses in X, Y and Z direction, including temperature and pressure stresses, shall be derived. For pressure vessels, both primary membrane and secondary bending stresses resulting from internal pressure shall be calculated to account for the effects of design discontinuities and design geometries. Where applicable, rotational accelerations shall be considered in addition to translational accelerations. Residual stress due to fabrication, assembly, welding, testing or preloading shall also be included.

**d. Derivation of a stress spectrum by use of the load events identified under a. and the stresses derived under c.:**

a stress spectrum shall be generated for each analysis location, and shall include the stresses for all loading events which occur throughout the service life. Each stress step in the stress-spectra has to contain the number of cycles in the step, the upper value of the stress amplitude and the lower value of the stress amplitude.

**e. Derivation of material data:**

material properties used in the analytical evaluation shall be valid for the anticipated environment, grain direction, material thickness, specimen width and load ratio (R). Material data shall be used as follows:

1. mean values of crack growth rate,  $da/dN$ ,  $da/dt$ ;
2. mean value of threshold stress intensity range,  $K_{th}$ ;
3. lower boundary values, defined as 70 % of mean values for:
  - (a) critical stress intensity factor,  $K_{IC}$  or  $K_{IC}$  (fracture toughness);
  - (b) environmentally controlled threshold stress intensity for sustained loading,  $K_{ISCC}$ .

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## 7.4 WELDS

- a. For welds, the fracture mechanics analysis shall be performed with the aid of the material properties applicable to the weldments, including weldment repairs.
- b. When such material properties are not available, they shall be derived by means of a test programme covering:
  1. ultimate and yield strength and Young's modulus for all welding conditions used, including mechanical properties (as above) in the presence of different mismatches, angles between joints or typical defects, so that their impact on the material degradation can be evaluated with respect to the strength requirements;
  2. the fracture toughness  $K_{IC}$ , the stress-corrosion cracking threshold  $K_{ISCC}$ , and crack propagation parameters for each type of thickness to meet the requirements for structural integrity and leak-before-burst, if applicable. These tests shall be performed on a sufficient number of specimens agreed with the customer to permit a statistical evaluation of final values.
- c. Any residual stresses, both in the weld and in the heat-affected zone, shall be accounted for.
- d. Even though inspected for embedded cracks, the initial crack geometry for the analysis shall always be assumed to be a surface part-through-crack or through-crack.

## 7.5 COMPOSITES

Potential fracture critical items made of fibre-reinforced composite or non-metallic material including bonded joints and potted inserts, other than glass, shall be treated as fracture critical items. They shall comply with the following requirements:

- a. **For fail-safe items.** An item shall not be accepted as a fail safe item unless:
  1. it meets all the requirements for the fail safe approach;
  2. it has been demonstrated that, for the item, there is no unacceptable degradation of the alternative load path, due to cyclic loads or environmental effects.
- b. **For safe life items.** An item shall not be accepted as a safe life item unless:
  1. it has been demonstrated by fatigue analysis supported by tests that, during a time period of four times the service life, there is no unacceptable degradation due to cyclic loads or environmental effects in the presence of induced defects, compatible with NDI techniques. Tests shall be performed with representative coupons;
  2. it undergoes a proof-test of all flight hardware to not less than one and two tenth (1.2) times the limit load.

Special problems can arise in certain instances such as a region of high load transfer where compliance with the proof test requirements for the composite structure introduces local yielding of the metal component. These shall be treated on a case by case basis. The test and analysis programme is subject to customer approval.

## 7.6 ROTATING MACHINERY

For Fracture Control purposes, a rotating mechanical assembly that has kinetic energy of 14240 ft-lbs (19307 joules) or greater (based on  $0.5 \cdot m \cdot v^2$ ) shall be considered, by definition, fracture critical.

Rotating machinery shall be proof (spin) tested and subjected to NDI before and after proof testing. The proof test factor shall be derived by means of fracture mechanics analysis.

Rotating hardware not defined as rotating machinery according to chapter shall be treated as any structural item.

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## 7.7 GLASS

- a. The design of all potential fracture critical glass components shall include an evaluation of flaw growth under conditions of limit stresses and the environments encountered during their service life.
- b. A fracture mechanics analysis for possible sustained crack growth ( $da/dt$ ) shall be performed for each glass item. This analysis shall demonstrate that the item sustains after four (4) times its service life at least one and four tenths (1.4) times the design limit load without fracture.
- c. The initial flaw depth used for design and analysis of glass items:
  1. shall not be smaller than three (3) times the detectable flaw depth based on the NDI methods used;
  2. shall be subject to approval by the customer. Long flaws with respect to depth shall be used for analytical life predictions. When using NASGRO, the aspect ratio  $a/c = 0.1$  shall be applied. Crack growth properties at 100% moisture shall be used for life predictions.
- d. Proof testing or NDI, consistent with the loading expected during service life, shall be conducted to screen for manufacturing flaws in each potential fracture- critical item based on the result of the fracture mechanics analysis.
- e. Proof testing is required for acceptance of pressurised glass components (such as windows and viewports) to screen the flaws larger than the initial flaw depth. The minimum proof pressure for these components shall be two (2) times the limit pressure.  
Proof testing shall be performed in an environment suitable to limit flaw growth during test.
- f. It shall be demonstrated that glass inside a habitable area shall be safe from breakage, or shall be contained, or released particles shall be smaller than 50  $\mu\text{m}$ . Positive protection for the crew against any breakage or release of shattered material is required.

## 7.8 FASTENERS AND SHEAR PINS.

Fasteners and shear pins may be classified as low risk fracture parts when, though they are not shown to be compliant with 4.2.2.3 of RD 14, (a) fracture of the fastener does not result in a single-point direct catastrophic failure, and (b) they can meet the following requirements:

- a. Be high-quality military standard, national aircraft standard, or equivalent commercial fasteners or pins that are fabricated and inspected in accordance with aerospace-type specifications. Fasteners, which require specific tensile preload and which are used in joints that are loaded primarily in tension, shall have rolled threads meeting aerospace or equivalent rigorous standards.
- b. Be fabricated from well-characterized metal which is not sensitive to stress-corrosion cracking. Bolts in tension applications shall not be fabricated from low fracture toughness alloys (as defined in 3.27) or specifically, Ti-6Al-4V STA titanium.
- c. Meet appropriate requirements for stress and fatigue analysis including torque/preload requirements for tension-loaded fasteners (i.e., sufficient preload to prevent gapping so that the cyclic loads are limited).
- d. Be of equal aerospace quality and meet all applicable criteria in a, b, and c above when reworked or custom-made fasteners.
- e. Have positive back-off prevention consistent with their criticality to assure the validity of fracture control of all fasteners.

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## 8. MATERIAL SELECTION GENERAL REQUIREMENTS

### 8.1 ALLOWABLE MECHANICAL PROPERTIES OF STRUCTURAL MATERIALS

Materials used in the fabrication of payload hardware shall be selected by considering the operational requirements for the particular application and the engineering properties of the candidate materials.

Allowable mechanical properties of structural materials shall be obtained from authoritative sources, such as MIL-HDBK-5, "Metallic Materials and Elements for Aerospace Vehicle Structures" and MIL-HDBK-17, "Plastics for Flight Vehicles," or other sources which provide reliable and statistically valid data. Structural mechanical properties shall be determined by analytical methods described in MIL-HDBK-5.

Material "A" or equivalent allowable values shall be used for pressure vessels and for all applications where failure of a single load path could result in the loss of structural integrity in a fracture-critical structure. Material "B" or "S" or equivalent allowable values may be used in redundant structures in which the failure of a structural element would result in the safe redistribution of applied loads to other load-carrying structures.


### 8.2 MATERIAL SAFETY CHARACTERISTICS

Materials used in the construction of ISS payloads shall meet certain material safety characteristics as required by NSTS 1700.7 and NSTS 1700.7, ISS Addendum, paragraphs 208.3 and 209 in their entirety. The material safety characteristics which shall be addressed per NSTS 1700.7 ISS Addendum include Stress Corrosion Cracking, Materials Compatibility, Flammability, and Toxic Offgassing. In addition, galvanic corrosion and Thermal Vacuum Stability (if applicable) shall be addressed. Potential structural erosion (e.g., plasma environmental effects, atomic oxygen, etc.) shall be considered in the design and analysis of ISS payloads, as applicable.

### 8.3 MATERIALS SAFETY CHARACTERISTICS SELECTION CRITERIA

Whenever possible, materials shall be selected that meet the acceptance test criteria for a particular characteristic. Existing test data are compiled in NASA's Materials and Processes Technical Information System (MAPTIS) electronic database. This database contains an alpha "rating" indicating acceptability for the individual characteristics for each material.

A hardcopy version of the MAPTIS database is published periodically as a joint document between MSFC and Johnson Space Center (JSC), MSFC-HDBK-527/JSC 09604, Materials Selection List for Space Hardware Systems. The MAPTIS database is managed by the Materials and Processes Laboratory at MSFC.

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## 9. QUALITY ASSURANCE REQUIREMENTS

### 9.1 NON-DESTRUCTIVE INSPECTION

#### 9.1.1 GENERAL

Relevant non-destructive inspection (NDI) levels shall be categorized as standard NDI, special NDI or proof testing NDI.

#### 9.1.2 NDI CATEGORIES VERSUS INITIAL CRACK SIZE

The initial crack sizes as defined in the following shall apply:

- Table 1 defines the initial crack sizes for standard NDI;
- Table 2 defines the initial crack sizes for standard NDI that shall be applied in the case of welds and castings;
- Initial crack geometries are shown in Figure 9-1

##### a. Standard NDI

This level of inspection requires the use of one or more of the standard industrial NDI techniques: dye-penetrant, X-ray ultrasonic or eddy current. Visual inspection is not acceptable, except for glass items. Standard NDI shall be performed in accordance with MIL-I-6870 and shall provide crack detection to at least 95 % confidence and 90 % probability level. Table 9-1 and Table 9-2 give, for various NDI techniques and part geometries, the largest crack sizes that can remain undetected at these probability and confidence levels.

##### b. Special NDI

This level of inspection shall be used only in special cases where limited life is demonstrated and serious problems can occur as a result of redesign or acceptance of the limited life. A statistical demonstration of 90 % probability and 95 % confidence shall be performed for the method. The demonstration results and resulting procedures shall be subject to customer approval. Such demonstration shall be carried out on specimens representative of the actual configuration to be inspected.

##### c. Proof testing NDI

Proof testing of a flight item is acceptable as a screening or inspection technique for cracks. However, proof testing can require loads substantially in excess of those usually imposed on flight hardware in order to screen out flaws of sufficiently small size. In the proof tests performed, procedures and stress analysis predictions shall be sufficiently reliable and coordinated to ensure that the predicted stress level and distribution are actually achieved, and that the absence of test failure ensures that the cracks of the sizes to be screened out are not present in any critical location or in any orientation of the item. Proof-test procedures shall be submitted to the customer for approval prior to the start of testing.



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## U.S. Customary Units (in.)

Crack Location	Part Thickness, t	Crack Type	Crack Dimension a	Crack Dimension c
<u>Eddy Current NDE</u>				
Open Surface	$t \leq 0.050$ $t > 0.050$	Through	t	0.050
		PTC <sup>1</sup>	{ 0.020	{ 0.100
			{ 0.050	{ 0.050
Edge or Hole	$t \leq 0.075$ $t > 0.075$	Through	t	0.100
		Corner	0.075	0.075
<u>Penetrant NDE</u>				
Open Surface	$t \leq 0.050$ $.050 < t < .075$ $t > 0.075$	Through	t	0.100
		Through	t	0.15-t
		PTC	{ 0.025	{ 0.125
			{ 0.075	{ 0.075
Edge or Hole	$t \leq 0.100$ $t > 0.100$	Through	t	0.100
		Corner	0.100	0.100
<u>Magnetic Particle NDE</u>				
Open Surface	$t \leq 0.075$ $t > 0.075$	Through	t	0.125
		PTC	{ 0.038	{ 0.188
			{ 0.075	{ 0.125
Edge or Hole	$t \leq 0.075$ $t > 0.075$	Through	t	0.250
		Corner	0.075	0.250
<u>Radiographic NDE<sup>2</sup></u>				
Open Surface	$.025 \leq t \leq 0.107$ $t > 0.107$	PTC	0.7t	0.075
			0.7t	0.7t
<u>Ultrasonic NDE<sup>3</sup></u>				
Open Surface	$t \geq 0.100$	PTC	{ 0.030	{ 0.150
			{ 0.065	{ 0.065
			{ 0.065	{ 0.065

**NOTE 1:** The crack configuration numbers refer to the crack configurations shown in Figure 9-1

**NOTE 2:** Radiographic NDI defect sizes are not applicable for very tight defects such as: forging defects, heat treatments induced defects, defects in compressive stress field. For such cases special NDI requirements apply.

Table 9-1 Initial crack size summary, standard NDI



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SI Units (mm)

Crack Location	Part Thickness, t	Crack Type	Crack Dimension a	Crack Dimension c
<u>Eddy Current NDE</u>				
Open Surface	$t \leq 1.27$	Through	t	1.27
	$t > 1.27$	PTC <sup>1</sup>	{ 0.51	{ 2.54
			{ 1.27	{ 1.27
Edge or Hole	$t \leq 1.91$	Through	t	2.54
	$t > 1.91$	Corner	1.91	1.91
<u>Penetrant NDE</u>				
Open Surface	$t \leq 1.27$	Through	t	2.54
	$1.27 < t < 1.91$	Through	t	3.81-t
			{ 0.64	{ 3.18
Edge or Hole	$t > 1.91$	PTC	{	{
			{ 1.91	{ 1.91
Edge or Hole	$t \leq 2.54$	Through	t	2.54
	$t > 2.54$	Corner	2.54	2.54
<u>Magnetic Particle NDE</u>				
Open Surface	$t \leq 1.91$	Through	t	3.18
	$t > 1.91$	PTC	{ 0.97	{ 4.78
			{ 1.91	{ 3.18
Edge or Hole	$t \leq 1.91$	Through	t	6.35
	$t > 1.91$	Corner	1.91	6.35
<u>Radiographic NDE<sup>2</sup></u>				
Open Surface	$0.64 \leq t \leq 2.72$	PTC	0.7t	1.91
	$t > 2.72$		0.7t	0.7t
<u>Ultrasonic NDE<sup>3</sup></u>				
Open Surface	$t \geq 2.54$	PTC	{ 0.76	{ 3.81
			{	{
			{ 1.65	{ 1.65

Table 9-2 Initial crack size summary, standard NDI



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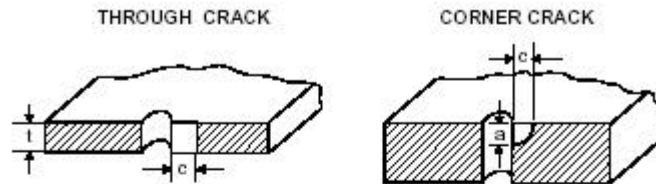
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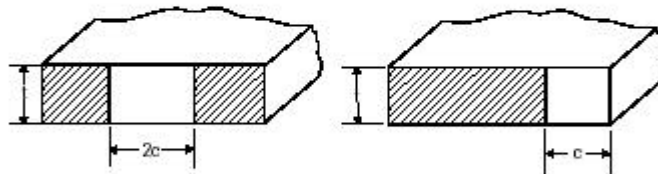
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## GEOMETRIES FOR CRACKS AT HOLES



## GEOMETRIES FOR CRACKS NOT AT HOLES

### THROUGH CRACKS



### PARTIALLY THROUGH CRACKS

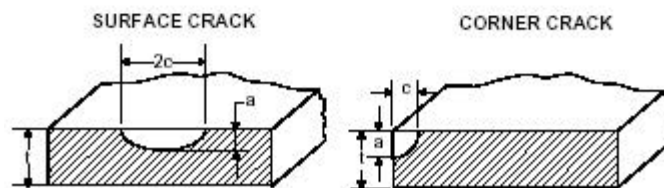



Figure 9-1 Initial crack geometries for parts

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## 9.2 INSPECTION REQUIREMENTS

The fracture control programme requires inspection of all PFCIs in order to validate the analytical life predictions and to permit hardware to be released as acceptable. Such inspection shall include at least:

- a. Inspection of raw materials for all safe life and fail-safe items to ensure absence of embedded defects larger than the assumed initial defect sizes.
- b. Initial inspection of all finished items by the NDI method (subclause 10.3) relevant to the assumed initial crack size. The NDI shall be performed for the total item even though only one location is analysed. Items to be inspected using dye-penetrant, shall have their mechanically disturbed surfaces etched prior to inspection. Rolled threads shall not be etched.
- c. Inspections as may be required for limited life items.
- d. Verification of structural redundancy for fail-safe items before each flight.
- e. Post test NDI for all proof-tested items. Concurrence of the customer is required where post proof test NDI is not considered practicable.
- f. Inspection of all welds shall include a search for surface defects as well as embedded defects.
- g. 100% inspection of all fusion joints of pressurized lines before and after proof test, using a qualified NDI method.
- h. Applicable NDI requirements shall be stated on design and manufacturing documentation. Inspection shall be performed by qualified personnel, certified for the relevant inspection method, in accordance with MIL-STD-410 or equivalent. Special jigs, fixtures and non-standard equipment needed to perform reinspection shall be deliverable with the fracture-critical items.

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## 9.3 TRACEABILITY


### 9.3.1 GENERAL

Traceability of structural materials and items shall be implemented to provide assurance that the material used in the manufacture of structural hardware has properties fully representative of those used in the analysis or verification tests. Traceability shall also provide assurance that structural hardware is manufactured and inspected in accordance with the specific requirements necessary to implement the fracture control programme. The traceability requirements of RD 14 shall be applied.

### 9.3.2 REQUIREMENTS

The following traceability requirements apply:

- all associated drawings, manufacturing and quality control documentation shall identify that the item is a potential fracture-critical item;
- each fracture-critical item shall be traceable by its own unique serial number;
- each fracture-critical item shall be identified as fracture-critical on its accompanying tag and data package;
- for each fracture-critical item a log shall be maintained, which documents the environmental and operational aspects (including fluid exposure for pressure vessels) of all storage conditions during the life of the item;
- for each fracture-critical item a log shall be maintained, which documents all loadings due to testing, assembly and operation, including torquing of fasteners.

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## 10. TEMPLATES

### 10.1 FRACTURE ANALYSIS RESULT SUMMARY TEMPLATE

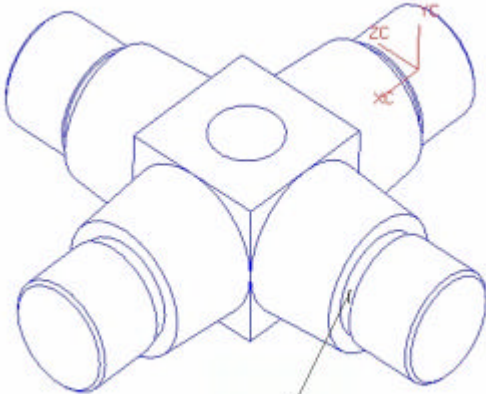
Project: TBD				FCI No TBD	
Structure: TBD				Classification : TBD	
Part Name : TBD				Criticality : TBD	
<div style="text-align: center;"> <p>Sketch for crack location</p>  <p><b>Crack Location</b></p> </div>				Location Code : TBD	
				Drawing No: TBD	
				NASGRO crack model: TBD	
				Geometry [ mm ] :	
				W : TBD	T : TBD
				B : TBD	D : TBD
				L : TBD	D <sub>0</sub> : TBD
				Material: TBD	
Unit Stress [Mpa]	Tension	Bending-1	Bending-2	Point	Biaxial
X					
Y					
Z					
Φ					
Θ					
Ψ					
Pressure					
Constant					
Max Stress ( in the spectrum ) [MPa] σ <sub>max</sub> = TBD		Material yield stress [MPa] σ <sub>y</sub> = TBD		Critical stress intensity [MPa vmm] K <sub>c</sub> = TBD	
Initial Crack Size [mm] a = TBD      c = TBD		Final Crack Size [mm] a = TBD      c = TBD		Critical Crack Size [mm] a = TBD      c = TBD	
NDI Sta: TBD		Analytical life : TBD		Analytical life > 4 times the service life? Yes:      No:	
CONCLUSIONS AND COMMENTS: TBD					

Table 10-1 PFCI Analysis Summary template

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## 10.2 PFCI LIST TEMPLATE

PFCI NO	ITEM NAME	TYPE	CRITICALITY	DWG. NO	MATERIAL	TYPE OF CONSTRUCTION	TYPICAL THICKNESS [MM] ( USED FOR ANALYSIS	LOAD TYPE	FRACTURE CLASSIFICATION	NDI
TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

Table 10-2 Potential Fracture Critical Item List template

Columns are defined as:

**PFCI No** : Potentially fracture critical item identification number

**Item Name** : Name of the item

**Type**:

Part: monolithic part

Conn:Connection between parts ( threaded bolt)

Mech: Mechanism assembly

**Criticality** :

Catastrophic: loss of life, disabling or fatal personnel injury. loss of orbiter or STS\ISS equipment

Non disabling personnel injury Major damage to STS\ISS equipment. Use of unsheduled saving procedures affecting operations of orbiter, ISS or other payloads

**Crack locations**: list of locations on part analyzed for fracture.

**Dwg. No** : number of drawing

**Material** : Material used for item manufacturing

**Type of Const** : manufacturing method

**Typical Thickness** : Typical Thickness of item

**Load Type** : Load applied to the item

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#### Fracture Classification :

**fail safe:** a PFCI can be considered fail safe if it is redundant and in case of failure the remaining structure is able to sustain the loads. Fatigue analysis is performed to ensure that the remaining items have sufficient strength to sustain the new limit loads completing the mission, for the HMA this approach is used for all the structural bolts, considering the fatigue life of the connected parts already covered by crack growth analysis.

**safe life:** a PFCI can be considered safe life if the greatest undetected flaw is not critical during specified life. Fracture mechanics analysis is performed to ensure that the analytical life is more than 4 times the service life.

**Contained/Restrained:** a PFCI can be considered contained if detachment caused from failure do not cause penetration of the containment walls/structure.

**NDI:** US ( ultrasonic ) , DP ( dye penetrant ) LA ( lot acceptance )

## 10.3 FCI LIST TEMPLATE

PFCI NO	ITEM NAME	TYPE	CRITICALITY	DWG. NO	MATERIAL	TYPE OF CONSTRUCTION	TYPICAL THICKNESS [MM] (USED FOR ANALYSIS)	LOAD TYPE	FRACTURE CLASSIFICATION	NDI	Analysis reference	Analytical life
TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

*Table 10-3 Fracture Critical Item List template*

Additional columns with respect to PFCIL are defined as:

**Analysis reference:** Document and section for item analysis

**Analytical life:** Life of the item resulting from analysis